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INDUCTION MOTOR PARAMETER IDENTIFICATION FROM OPERATIONAL DATA

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Abstract

Among the parameters of an induction motor, the dynamics are largely characterised by Inertia (H) and torque-damping factor (B). It is now simple to get substation bus bar data (current and voltage) by using phasor measurement device. This paper uses that data to identify an induction motor model in frequency domain and from the model of the induction motor one can estimate B and H. In this paper estimation of parameter B and H from the frequency domain model of an induction motor is shown for a fan load by using simulation model and also a 1.5kW real motor in a Queensland University of Technology (QUT) laboratory.

1. Introduction

Induction motors undergo transients when voltage, current and speed vary therefore it is important to understand dynamic characteristic of the motor for their influence on power system dynamics. Inertia and torque damping factor are the key influential parameters for the dynamic nature of induction motor. Hence in this paper the value of B and H are estimated from the Bode plot of an induction motor transfer function aiming to study their influence to power system and vice-versa. This frequency domain model is obtained using correlation techniques. Papers [1-20] estimate induction motor modelling and parameters without considering the major effect that load change influence the power system as well power system change effect the load. The authors of those papers have used a feed forward model (power system affects load) but in this paper the feedback loop (where load is effecting the power system) in addition to the normal feed forward element is being considered. Paper [2] has considered feedback loop and estimated transfer function of the power system not the transfer function of load. In that paper [2] the author mentioned that it is important to identify the more significant load. Approximately 50-60% of electric energy is consumed by induction motors in a power system therefore the induction motor is a significant load and this paper is interested in the dynamic characteristic of the induction motor. Papers [1-23] consider the changes of the power system as

measurement noise but in this paper the change of power system and change of load are considered as major information to develop the model of the induction motor and the theory for identification of a system under feedback with multiple noise is already developed in paper [23] which is used in this paper.

For estimating the parameters of the system, the system model is important. Paper [17] described some model of induction motor and also described that 1st order quasi stationary model is good for determine response to disturbance up to 2 Hz and for disturbances with some higher perturbation frequency the motor can be treated as third order model which neglect the stator transient. Aiming to model induction model in the frequency band which effect the generator oscillation, this paper simulates in time domain. For obtaining time domain the simulation has used a 3rd order induction motor model. After simulation we transfer the 3rd order data to frequency domain. Also we decompose the third order to an equivalent 1st order model by ignoring the rotor transient. Then map the 1st order to steady state algebraic equation to determine the parameter value.

There are different types of test methods performed on motor and these are off-site methods, onsite and off-line methods. In off-line, test the motor separately from its application side (no load and locked rotor test) and Onsite and offline methods test are performed with the motor already connected in the industrial setup and supplied by its power converter [4]. On-line

methods are concerned usually with rotor parameter and assume other parameter known [4]. B and H are the main parameter estimated in this paper using an online method in this paper. Also, the on-site method is good for small perturbations and this paper consider small perturbation around steady state of voltage and frequency as input with real and reactive power change as output.

An experiment has been conducted up in Queensland University of Technology Laboratory for the purpose of this research. A phasor measurement device has been used for measuring the system transient data and a 16 bit data acquisition card is used to acquire the data.

The paper is organized as follows. Section II calculates the induction motor model and introduces the 3rd order model and decomposes the 1st order model from the 3rd order model. Section III describes algebraic equation to identify the parameters. Section IV presents a simulated result in frequency domain and from that plot to estimate the value of B and H. Section V describes the experimental results and section VI the conclusion.

2. Induction motor transfer function [23]

The block diagram of the interaction between power system and an Induction motor load is shown in fig.1. W1 is the white noise in frequency or voltage of the power system and W2 is the white noise of the P or Q of the Induction motor. These two variables indicate the disturbance of the power system and the load. The symbol X is the voltage (v) or frequency (f)/angle (ω) changes in power system and Y is the real (P) or reactive (Q) power changes of the induction motor load.

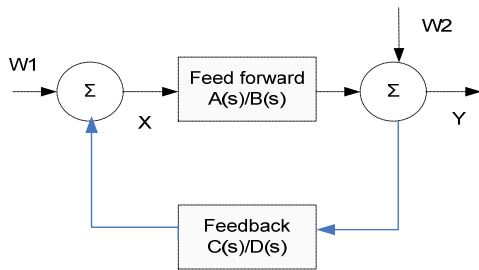


FIG.1 Multinoise feedback model

The real power model of the induction motor by changing voltage/ supply frequency is presented here for the voltage case

$$G = \frac{\Delta p}{\Delta v} = \frac{G_1}{G_2} = \frac{S_{w_1 p}}{S_{w_1 v}}$$

Similarly, reactive power model of induction motor by changing voltage/supply frequency is,

$$G = \frac{\Delta q}{\Delta v_s} = \frac{G_1}{G_2} = \frac{S_{w_1 q}}{S_{w_1 v}}$$

To fit this model to the induction motor model, the 3rd order induction motor is simulated in matlab. Third order model is derived from 5th order by ignoring the stator transient. The equations of third order model in synchronous reference frame are [24],

$$\begin{bmatrix} \frac{\Psi_{dr}}{\Psi_{qr}} \end{bmatrix} = Ar \begin{bmatrix} V_{dr} \\ V_{qr} \end{bmatrix} + Br \begin{bmatrix} V_{ds} \\ V_{qs} \end{bmatrix} + Cr \begin{bmatrix} \Psi_{dr} \\ \Psi_{qr} \end{bmatrix}$$

$$\overline{\omega_r} = \frac{\omega_b}{2H} (T_e - T_l)$$

Where,

ω_r, ω_b Angular velocity of rotor and power system in rad/s.

T_e Electromagnetic torque

T_l Load torque

$\overline{\omega_r}$ Derivative of rotor angle

$\overline{\Psi_{dr}}$ Derivative of Direct – axis flux

$\overline{\Psi_{qr}}$ Derivative of quadrature – axis flux

V_{ds} Direct – axis stator voltage

V_{dr} Direct – axis rotor voltage

V_{qs} quadrature – axis stator voltage

V_{qr} quadrature – axis rotor voltage

Ar, Br and Cr matrix with fixed components

If ignoring the stator transient the 1st order induction motor model is,

$$\begin{bmatrix} 0 \\ 0 \end{bmatrix} = Ar \begin{bmatrix} V_{dr} \\ V_{qr} \end{bmatrix} + Br \begin{bmatrix} V_{ds} \\ V_{qs} \end{bmatrix} + Cr \begin{bmatrix} \Psi_{dr} \\ \Psi_{qr} \end{bmatrix}$$

$$\overline{\omega_r} = \frac{\omega_b}{2H} (T_e - T_l)$$

3. Algebraic Equation

Consider here the steady state of induction motor model, as shown in fig .2.

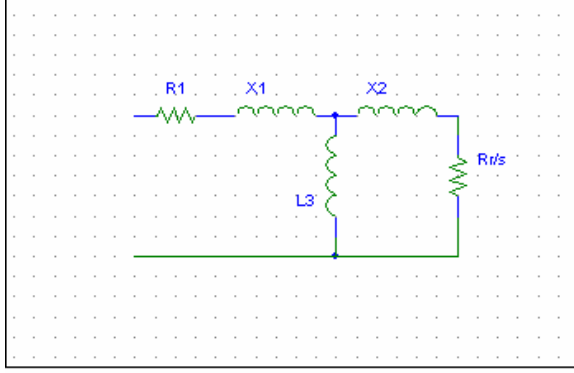


FIG.2 Steady-state Induction motor circuit diagram

The slip of induction motor is,

$$S_l = \frac{\omega_s - \omega_r}{\omega_s} \quad (1)$$

From the above circuit, if ignore the mutual inductance, the current equation is,

$$I = \frac{V}{\frac{R_r}{S_l} + R_1 + jX} \quad (2)$$

Using the value of I, real and reactive power of the induction motor is,

$$P_e = \text{Real}(VI^*) \quad (3)$$

$$Q_e = \text{Imag}(VI^*) \quad (4)$$

We model the shaft load as linear so the dynamic motion equation is,

$$P_m = B \omega_r \quad (5)$$

$$\frac{d\omega_r}{dt} = \frac{P_e - P_m}{2H} \quad (6)$$

Where

S_l : Slip of an induction motor

ω_s : Synchronous speed of the bus (P.U)

ω_r : Angular frequency of rotor (P.U)

I: Current (P.U)

V: Bus voltage (P.U)

R_1 : stator resistance

R_r : Rotor Resistance

X_1 : stator reactance

X_2 : Rotor reactance

X : $X_1 + X_2$

X_m : magnetizing reactance

P_e : Real power of induction motor (p.u)

Q_e : reactive power of the induction motor (p.u)

B: Mechanical torque coefficient (p.u)

H: Inertia constant (p.u torque/p.u speed)

P_m : mechanical power (p.u)

By using induction motor continuous state space model (5) and (6) and assuming that the slip of induction motor is working in linear region of torque –speed curve and also input bus frequency is perturbing with white noise, can find out the linear time invariant transfer function

$$\frac{\Delta P_e}{\Delta f} = K_f \frac{s + Z}{s + P}, \quad s = \text{Laplace transform}$$

Where,

$$K_f = \frac{V^2}{R_r \omega_s}, \quad (8)$$

Here V_0 , s_{l0} are the steady state voltage and slip of an induction motor.

$$Z = \frac{B}{2H} \quad (9)$$

zero of the transfer function

$$P = \frac{B}{2H} + \frac{V_0^2}{2HR_r \omega_s} \quad (10)$$

pole of the transfer function

Similarly

$$\frac{\Delta Q_e}{\omega_v} = \frac{2s_{l0} V_{qs0}^2 X}{R_r^2 \omega_b} \left(\frac{S + \frac{B}{2H}}{\left(S + \frac{B}{2H} + \frac{v_{qs}^2}{2HR_r \omega_b} \right)} \right)$$

4. Simulation Result

3-phase, 10HP motor with following parameters values is used for simulation in MATLAB.

B	H	R _r	R _l	X ₂	X _l	X _m
0.5	0.5	0.0222	0.0453	0.0322	0.074	2.042

Frequency domain plot of 3rd order and 1st order real power transfer function of the induction motor between V and P is as shown in fig.3

From the plot,

The location of zero is 0.4842

The location of pole is 78.37

The gain is -11db

$$-20\log A = -11$$

$$K_f = 0.2724$$

The algebraic equation of 1st order transfer function is,

$$K_f = 1.5 \frac{V^2}{R_r \omega_b}$$

Here V=1.414 pu

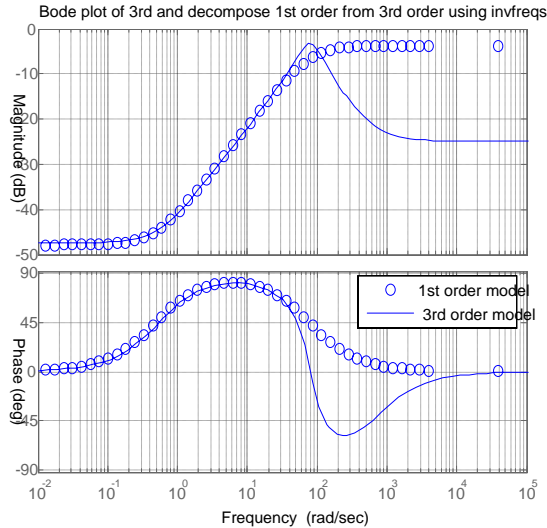


FIG.3 Bode plot of 1st and 3rd order model simulated in Matlab

The way to find out pole and zero location from 1st order transfer function is as shown in fig.4.

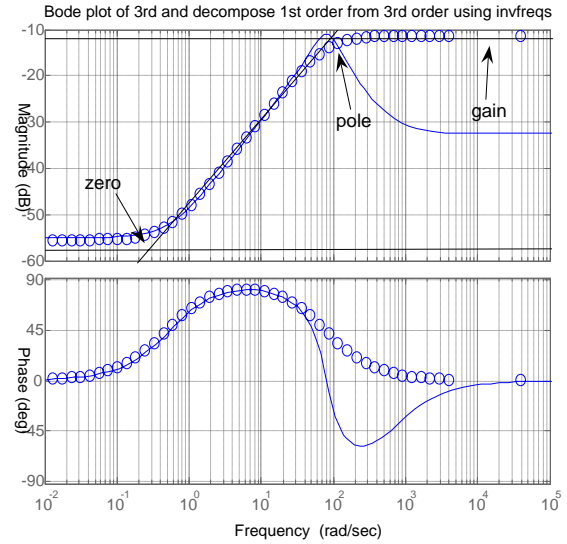


FIG.4 Bode plot of 1st and 3rd order model

$$\omega_b = 377 \text{ rad / s}$$

$$R_r = 0.0292.$$

$$\text{Pole-Zero} = \frac{V^2}{2R_r H}$$

$$(78-.48) 2R_r = \frac{V^2}{H}$$

$$H = \frac{1.414 * 1.414}{(78 - .48) * 2 * 0.0292} = 0.441$$

$$\text{Zero} = \frac{B}{2H}$$

$$B = 0.48 * 2 * 0.441 = 0.423$$

5. Experimental result

A 1.5kw, 3-phase motor with shaft load of 1HP dc machine is running in the laboratory and a phasor measurement unit with 16bit data acquisition card is used to store the input voltage, current and phase. Real and reactive power is calculated by using these

data. Transfer function $G \left(\frac{\Delta P_e}{\Delta \omega_v}, \frac{\Delta Q_e}{\Delta \omega_v} \right)$ is

generated by using the theory developed in paper [23]. After transfer function is identified, fit it to 3rd order model and decompose 3rd model to 1st order model. Therefore compare the 1st order model pole and zero location to algebraic equation and estimate the value

of B and H. The real motor transfer function $\frac{\Delta P_e}{\Delta \omega_v}$ is

shown in fig.5

From fig.5

$K_f=0.8843$

Location of pole=0.04

Location of zero=0.002397

Put the values in Eqs (8-10),

The value of $H=7.840$

And $B=0.0375$.

Direct measurement of real power from the experiment setup is 0.035pu. As consider the rotor angular frequency is similar to system angular frequency. Therefore the value of B is equal to value of real power.

Experimental value of B and Estimated value of B almost exact.

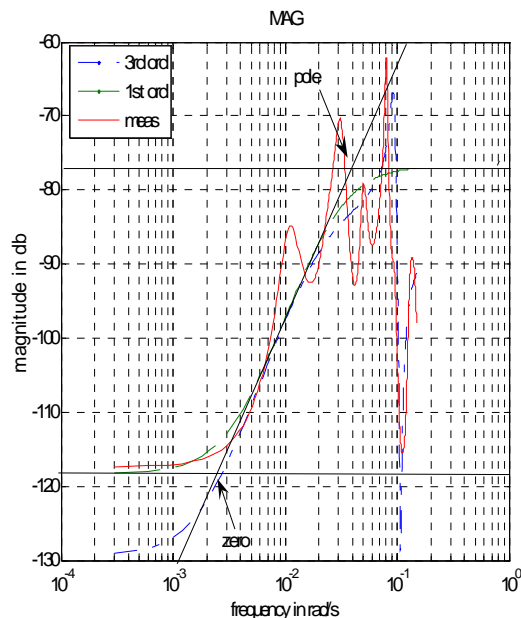


FIG.5 Bode plot of real, 1st order and 3rd motor run in experiment lab

The per unit inertia estimated from bode plot is 7.850s. In kg.m^2 the value is 0.954 kg.m^2 . The size of rotor used in experiment lab almost 1kg. Hence the estimation is of the correct order.

6. Discussion

The calculated value of B and H from bode plot are close to the exact value. INVREQZ command has been used for decomposing 3rd order induction model to 1st order model. INVREQZ command estimates model in frequency domain based on sampling frequency. Hence the accuracy depends on length of the data sequence. The longer the sample set, the

value gets more close to the accurate result. There is a drawback to get the exact value because more difficult to use long sample point because of memory limitations in MATLAB. Estimating parameter from bode plot is a quite accurate and easy method proved by estimated parameter of a real motor in QUT lab. This paper is successful to show that if power system operation data are available, using those data it is easy to plot Bode Plot and from Bode plot it is easy to calculate parameter values. Therefore, it is possible to identify the type of induction motor load in power system.

The method used for modelling induction motor is accurate enough to estimate the parameter value. If it is not accurate then parameters value can't predict the real motor parameters. Also the 3rd order model of a synchronously rotating reference frame is good choice to incorporate dynamic characteristic and variable operating data. In addition the linearized algebraic equation is accurate enough to compare with 1st order fit.

This paper is part of the thesis of "Composite Load Model Decomposition: Induction motors contribution". Hence future work would be to identify the frequency domain character of several groups of induction motors and to decompose the groups to parameters for each group of motors. There is also a need to decompose the composite load into

- (1) constant power load,
- (2) constant impedance load and
- (3) frequency dependent load (Induction motor).

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